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RES and risk: Renewable energy's contribution to energy security. A portfolio-based approach

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ABSTRACT

During the first decade of the 21st century, renewable energy sources (RES) had been gaining momentum due to environmental issues. Concerns about pollution and climate change have raised public awareness, encouraging governments to adopt policies to preserve and protect the environment. Regarding energy, RES promotion, together with energy efficiency measures, has been the main policy response to address such concerns. As a consequence, RES development during the first decade of the 21st century has been remarkable.

Although RES deployment has been mainly focused on achieving environmental goals, its potential contribution to energy security went not unnoticed. However, it is worth noting that while the trade-off between environmental goals – and the use of RES to accomplish them – and competitiveness has been widely explored, the relationship between energy security and RES has received less attention, both at the conceptual and energy policy levels. This article tries to address such a relationship. The present article focuses on renewable electricity imports as illustrated by the case of the Mediterranean Solar Plan.

After introducing the energy security/energy risk concept and its dimensions, the article focuses on the contribution of RES in terms of security of supply for a given energy mix using the portfolio theory. Most of the analyses of the interactions between RES and energy security focus on the national level, with RES being mainly conceived as a substitute for fuel imports to produce electricity and reduce so-called energy dependence. However, new transmission technologies allow the import of electricity directly from neighbouring countries far out of the range of regular electricity lines. Therefore, this article tries to broaden the analysis of energy security to international RES trade flows, applying the previous discussion to the main project involving significant international green electricity trade, the Mediterranean Solar Plan.

Contents

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1. Introduction

During the first decade of the 21st century, renewable energy sources (RES) had been gaining momentum due to environmental issues. Concerns about pollution and climate change have raised public awareness, encouraging governments, especially in developed nations, to adopt policies to preserve and protect the environment. Regarding energy, RES promotion, together with energy efficiency measures, has been the main policy response to address such concerns. As a consequence, RES development during the first decade of the 21st century has been remarkable: since 2004, investments in RES have increased more than tenfold, reaching 257 billion US dollars in 2011; from 2008 to 2011 almost half of the new power capacity added worldwide was of renewable origin [52–54].

Although RES deployment has been mainly focused on achieving environmental goals, its potential contribution to energy security went not unnoticed, highlighting the potential of RES to improve the security of energy supply in consuming countries. However, it is worth noting that while the trade-off between environmental goals – and the use of RES to accomplish them – and competitiveness has been widely explored [3,55], the relationship between energy security and RES has received less attention, both at the conceptual and energy policy levels despite its “symbiotic” nature [64]. However this topic has been increasingly covered last years with the publication of several country studies that highlight RES contribution to energy security. Among them we can include Germany [31], the Scandinavian countries [2], Turkey [8] or Taiwan [56].

This article tries to address this relationship explaining also the main differences between RES and conventional energy sources regarding energy security. While hydropower, bio-fuels, or rare earths metals are part of that relationship, the present article focuses on renewable electricity imports as illustrated by the case of the Mediterranean Solar Plan.

The article is organised as follows. The first section introduces the energy security/ energy risk concept and its dimensions, identifying the main differences between conventional fuels and RES in this regard. Section 3 briefly explains the basics of portfolio theory, the theoretical framework of the analysis. The third section focuses on the contribution of RES in terms of security of supply for a given energy mix. Considering the few international RES-generated electricity flows, most of the analyses of the interactions between RES and energy security focus on the national level, with RES being mainly conceived as a substitute for fuel imports to produce electricity and reduce so-called energy dependence. However, new transmission technologies allow the import of electricity directly from neighbouring countries far out of the range of regular electricity lines. Therefore, Section 5 tries to broaden the analysis of energy security to international RES trade flows. The following section applies the previous discussion to the main project involving significant international green electricity trade, the Mediterranean Solar Plan. The last section concludes.

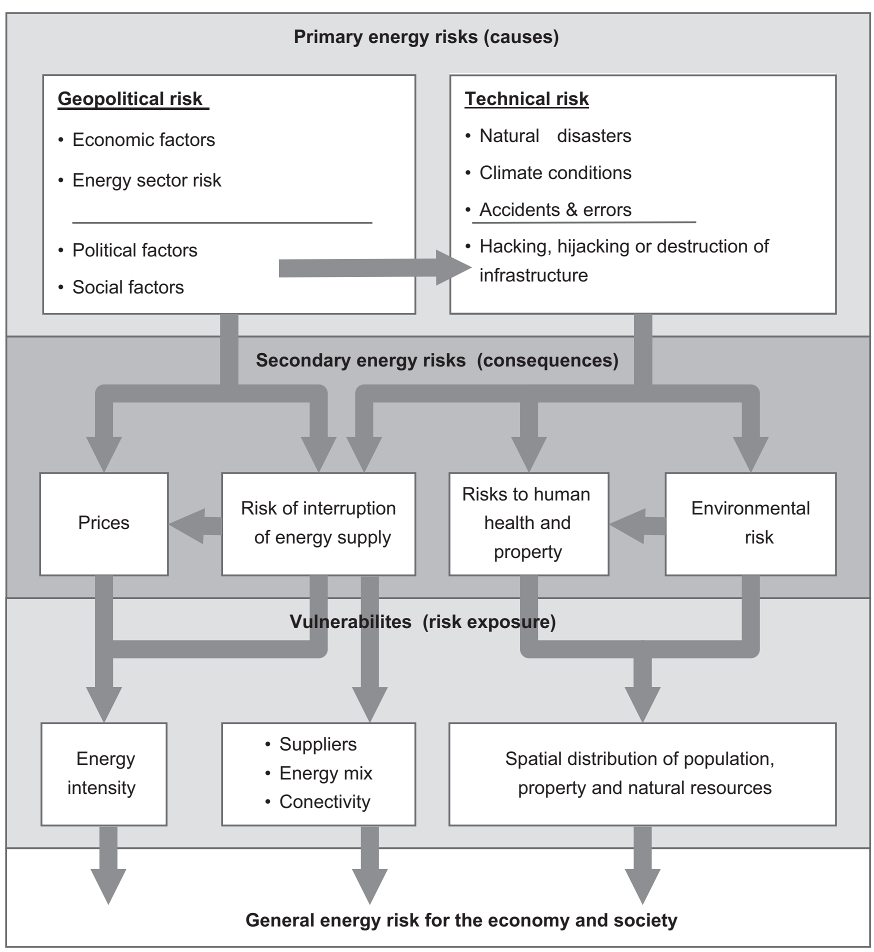

Fig. 1. A causal taxonomy of energy risk.
Source: adapted from García-Verdugo and San-Martín [27] (A first version of this figure was proposed in the REACCESS (*Risk of Energy Availability: Common Corridors for Europe Supply Security*) project. This project tried to optimise European energy supply at the corridor level using a techno-economic energy model that considers not only cost but also environmental restraints and energy risk. See acknowledgements at the end of the article, before the references.)

2. Energy security and energy risk

Energy security is a multifaceted concept that has been increasingly used since the beginning of the 21st century due to the combination of rising political unrest in some key energy-producing countries, the use of the 'energy weapon' by others, fears of resource competition and record oil prices. However, because the concept is not very specific, ambiguities and misunderstandings remain in its use in the energy policy domain. Most definitions – such as the one used by the UNDP [63], the European Commission [20] or the IEA [33] – do agree in three respects: the need to provide sufficient energy supply for economic activity to be conducted unhindered; the amount of energy needed being supplied continuously, without interruptions; and the need for affordable prices. The European Commission adds environmental sustainability as the fourth pillar of energy security, further linking RES development with energy security.

Because energy security cannot be measured directly, most of the literature focuses on energy risk, treating energy security and energy risk as the same.

There have been several attempts to classify energy risks, like those of Weisser [67], Fattouh [25], Gupta [28], Checci et al. [9] Doukas et al. [16], Sovacool [58], Winzer [68] and Johansson [36]. However, such studies tend to focus only on some of the dimensions of energy risk. Fig. 1 tries to explain the energy risk concept in a more comprehensive manner through some stylised causal relations.

The classification shown in Fig. 1 proposes a causal scheme of the various types of risk involved in energy security. The overall energy risk results from the aggregation of three different layers: causes or factors capable of interrupting supply (primary energy risks), their effects (secondary energy risks) and vulnerabilities.

Primary energy risks can be grouped into geopolitical factors and technical factors. Geopolitical risks are all those risks arising from the organisation of human activity in its main forms (economic, political and social activity) in the origin, transit or destination countries where the energy commodities flow. A fourth distinct category represents intrinsic energy risks, such as the reliability of proven reserves or the soundness of reservoir management policies in energy exporting countries. Technical risks, for their part, embrace all factors that might affect the normal function of energy infrastructure. On a second level, secondary energy risks include volatility of prices, interruption of supply, risks to human health and property and environmental risk. Considering the vulnerabilities involved, these four risks might ultimately create a general energy risk for the economy and society.

It is worth noting that although much attention has usually been given to the notion of energy dependence,[1] vulnerabilities are more relevant variables for policymaking, as noted by Kendell [37] or Alhajji and Williams [1]. Primary and secondary energy risks arising from energy exporting countries 'could' affect the economy or the well-being of a country; however, vulnerabilities tell us if the country 'is not going' or 'is going' to suffer, and how much, from these risks.

In the following paragraphs, the scheme shown in Fig. 1 will be used to briefly analyse the main differences regarding energy risk between conventional and unconventional energy sources.

Regarding energy risk, if electricity is generated and consumed domestically, the geopolitical risk of RES is assumed to be zero.[2] Furthermore, because domestic RES production substitutes for fossil fuel imports, the country can enhance its energy independence. However, if RES-generated electricity is imported, geopolitical risks must be reassessed. The main concern on this subject is whether an external supplier can use electricity as an 'energy weapon' similar to oil or gas. However, Lilliestam and Ellenbeck [41] rejected this possibility if the system maintains its buffers and if electricity imports are limited to 15% following the scenarios devised by Desertec.[3] The article will return to this issue in Section 5.

From a technical point of view, alternative energy sources that form the core of the RES portfolio (solar, wind and hydropower) cannot completely guarantee uninterrupted power supply. Because these energy sources depend upon weather conditions for electricity generation, some back-up capacities fuelled by fossil fuels are needed. However, RES enhance the technical resilience of the system due to energy mix and spatial diversification [64].

Decentralised RES facilities are less insecure than conventional facilities concerning physical failure or assault; however, these facilities face similar levels of risk arising from control network hacking. Since the revolution of information technologies (IT), the technical risk associated with these technologies is increasing because they are now ubiquitous [69]. Hacking the SCADA (Supervisory Control and Data Acquisition) system that is controlling energy facilities is easier (and safer) than attacking the facilities physically, providing one has the requisite IT skills. Although some authors have noted that RES growth [26] increases this type of risk,[4] the whole energy system and most non-energy networks (e.g., communications, transport and water systems) rely heavily on this type of IT systems. Thus research in cyber security issues is granted and solutions from other networks can be introduced in the energy system.

Despite geopolitical and technical risk differences between conventional and unconventional energy sources can be relevant, the main differences are related to secondary energy risks. First, RES do not need 'fuels' to produce power[5] and are thus not affected by price volatility in international energy markets, unlike oil, natural gas or coal. Furthermore, because RES are fixed-cost technologies, they could be used to balance price volatility inherent to fossil fuels, as will be shown in Section 4. Second, it is widely accepted that RES are cleaner than conventional energy sources. Third, with the only exception of hydropower, RES are considerably safer for the population, properties and natural resources than conventional energy sources in case of an accident. Thus, even if sustainability is not included in the energy security definition, the secondary risks of RES are lower than the risks faced by conventional energy sources.

[1] Energy dependence is usually defined as the share of energy imports in total energy consumption. A well-known example of the importance given to this concept is found in the EU's 2001 green paper *Towards a European strategy for the security of energy supply* [20].

[2] Most statistics (for instance, from the IEA) count renewable energy as 100% safe energy supply produced internally.

[3] In the first decade of the 21st century, following several studies from the German Aerospace Center, Desertec was designed as a project to generate renewable energy from MENA (Middle East and North Africa) countries transferring it through HVDC (High-Voltage Direct Current) lines to consumption centres in the EU-MENA region. Desertec Industrial Initiative (Dii) is the consortium of private companies created to promote the implementation of Desertec while the Mediterranean Solar Plan is the EU plan included in the Union for the Mediterranean (UfM) to promote renewable energy generation and trade in the Euromediterranean area. On 16th May 2012, the UfM and Dii signed a Memorandum of Understanding for future collaboration, as both institutions strive for the same long-term objective [61].
In Lilliestam and Ellenbeck's simulation, risk will increase only if North African electricity share climb above 15% or if the five North African countries join in a coordinated effort, which is highly improbable considering the current external relations.

[4] Wang and Lu [66] provide a deep analysis of security vulnerabilities and solutions for smart grids. The conclusion is that "Smart Grid requires fine-grained security solutions designed specifically for distinct network applications". Then it is possible to protect the grid but research and investment is needed to do so.

[5] The only exception among RES is biomass.

Finally, RES could reduce vulnerability through the energy mix and technological and spatial diversification. The latter could have an internal dimension because RES facilities in a country are located, for instance, in sunny and windy places; while conventional energy infrastructures are located following another completely different set of variables: proximity to demand centres, fossil fuel reserves, waterways or harbours. Moreover, RES-based decentralised power generation is less insecure than conventional energy sources to physical failure or assault as we have seen before. But the internal dimension is not the only option to reduce vulnerability using RES: there is also an external dimension if international RES imports flow from and through nations that are not currently supplying the destination country, as it is going to be seen in sections four and five.

In the end, efficiency and diversification are the keys to improve energy security reducing energy risk exposure, also known as vulnerability. As it has been seen in Fig. 1, vulnerabilities are the variables that determine the extent of the damage done by a disruption of energy supply. Thus improvements in efficiency and more diversification will have a direct impact in energy security. This article will deal with diversification through international RES flows.

From our point of view, diversification is the main failsafe of the energy system. However as there are several factors and multiple variables that could affect energy security or could cause energy supply disruptions (see Fig. 1), the diversification must reach every layer of the energy system. It is not enough to diversify suppliers geographically: energy sources, technologies, methods of transportation, etc., must also be diversified in order to have as many alternatives as possible to avoid, or lessen, supply disruption impacts. In this regard, international RES flows could contribute in several ways to energy security:

- Diversification of the energy mix by sources, as today fossil fuels produce most of the energy consumed in an average country.
- Geographical diversification of energy suppliers, given that international RES trade flows are today limited to a few cases.
- Diversification of means of transportation, as the electricity lines used will not be the regular AC (alternating current) lines, but HVDC (High Voltage Direct Current) ones.

Besides, international RES trade flows could increase connectivity with new countries allowing to reroute energy supplies or even to regionalise disruptions increasing the bargaining leverage in conflict resolution.

To sum up, every time a new item, with specific or different features from the rest, is added to the energy system the resilience of the system improves, increasing its ability to cope with an unexpected event threatening the energy supply. This fact could be easily explained using the portfolio theory[6] as it will be seen on the next section. Given that RES do not burn fossil fuels, their technologies are diverse and different, and have another set of features unlike conventional energy fuels regarding energy security, they would fit perfectly to the goal of reducing energy risk.

Having described the security related differences between conventional and unconventional energy sources, the next section explains the basics of portfolio theory, that will be used in Section 4 to address the contribution of RES to energy security.

[6] Eq. (2) shows the calculation of the variance of the portfolio. As it will be explained in next section, the key to reduce variance is the covariance. If two items are similar, there will be high probability to have a positive covariance. If both items are very different the probability to have a negative covariance increase; decreasing the overall variance.

3. Basics of the portfolio theory

Managing energy security implies hedging risks in an uncertain environment, such as future relative costs of alternative energy sources. To do so requires a comprehensive approach that includes uncertainty regarding future relative costs. Conventional wisdom states that RES are more expensive than conventional technologies and that deploying renewables will thus increase energy costs, both for electricity generation (wind, solar or others) and transport (bio-fuels or green electricity). However, this intuitive result is not necessarily true when considering uncertainty about future relative costs, especially fuel cost.[7] The economic theory of decision-making under uncertainty, widely applied to portfolio choice by finance theory, offers a different result. When applied to set the optimal contribution to the energy mix from different sources, each energy source should be valued not by its single profitability but according to its contribution to portfolio costs and benefits relative to its contribution to portfolio risks [4]. According to this approach, an optimal energy mix is characterised by two conditions: minimising expected costs at any given risk level while minimising expected risks for every level of expected costs.

Portfolio choice theory suggests that deploying RES will reduce total costs for any given level of risk. This result occurs because most RES are fixed-cost technologies that do not suffer from the cost volatility that affects conventional energies. More importantly, as explained in the previous section, RES costs are not affected by fuel price volatility and its variations (i.e., interest rates) tend to be uncorrelated with conventional energy costs. Thus, diversifying towards RES reduces the risk of future fossil fuel price increases. The optimality of RES portfolio standards or targets may be illustrated by the standard portfolio choice model initially developed by Markowitz [45].[8] According to Elton et al. [17] its analytical framework may be presented as follows.

Let μ and σ denote, respectively, the average return and the variance of this return, indicating with a bar over μ the expected return of the random variable; sub-indexes P, i and j, denote the portfolio (P), and its individual assets (i, j) of the n number of risky assets which form it and, finally, x_i is the share of asset i in the portfolio.

To define a portfolio, the mean variance model can be used. Thus, portfolio average return and the variance of this return are needed. The expected return on a portfolio of risky assets is a weighted average of the expected return on the individual assets (1), while in the calculation of the variance, covariances between pairs of assets (σ_{ij}) appear (2)

$$\bar{\mu}_P = E(\mu_P) = E\left(\sum_{i=1}^{n} x_i \mu_i\right) = \sum_{i=1}^{n} x_i \bar{\mu}_i \tag{1}$$

$$\sigma_P^2 = E(\mu_P - \bar{\mu}_P)^2 = \sum_{i=1}^{n} x_i^2 \sigma_i^2 + \sum_{i=1}^{n} \sum_{\substack{j=i \\ i \neq j}}^{n} x_i x_j \sigma_{ij} \tag{2}$$

First part of Eq. (2) represents the sum of the variance of the individual assets of the portfolio weighted by its share, while the second sum

[7] For instance, the merit-order effect that allows RES power to enter the electricity system before conventional energies (given their close to zero marginal cost and their inability to stock generated power) in a feed-in tariffs (FIT) system saved German consumers 5 billion euros in 2006 (rising from 1 billion in 2001) due to wind energy [55].

[8] For a deep explanation of the model see Varian [65], Fabozzi, Gupta and Markowitz [24] or Elton et al. [17]. This theory has been widely applied to energy economics; see, for instance, Muñoz et al. [47], Bazilian and Roques [7], Awerbuch et al. [5], Springer [59], Humphreys and McLain [32], Helfat [30] and Bar-Lev and Katz [6]. Figs. 2 and 3 are common depictions of the portfolio choice model.

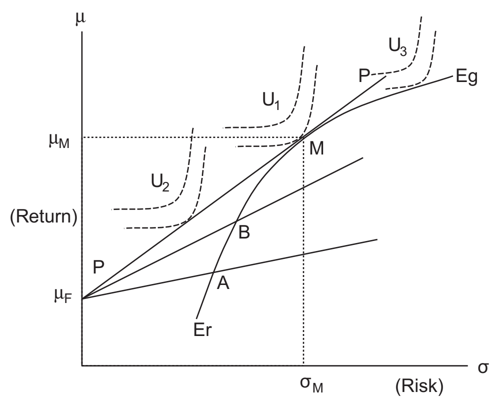

Fig. 2. The efficient frontier and the capital market line.

covariances. The first sum can be reduced selecting low risk assets, but the key to reduce the overall variance (and the risk) of the portfolio lies in the second part of the equation. Not correlated assets or negatively correlated ones, i.e., with a cero or negative covariance, would eliminate this part of expression (2) or even turn it negative, reducing the risk of the portfolio. Conventional energy sources and RES have this kind of relation. For instance, an increase in fossil fuel cost does not affect renewable energy return (covariance equal to cero) as RES do not need fuel. The implementation of a CO_2 emissions trading system would increase cost of conventional energy sources but would reduce RES cost in relative and even absolute terms. The latter will occur if some CO_2 emission allowances are allocated to RES facilities because they can sell the allowances permits as RES facilities do not emit CO_2.

Using Eqs. (1) and (2) all conceivable portfolios combining risky assets defined by its average return (μ) and its variance (σ^2) could be identified. However, not all of them would be considered by an investor as some portfolios offered a lesser return for the same risk or a higher risk for the same return. Discarding these portfolios, we obtain the "efficient frontier", being shown in Fig. 2 as the curve Er−Eg.

A rational investor will always choose portfolios in that efficient frontier, as it will maximise return for a given risk or minimise risk for a given return. Once the efficient frontier is obtained, the choice for each particular investor depends on his or her risk aversion, which could be represented by the regular set of utility curves (U_1, U_2 or U_3 in Fig. 2).

What would happen if there is a riskless asset? As the riskless asset has cero variance ($\sigma_F^2=0$), its fixed return (μ_F) must be plotted in Fig. 2 vertical axis. Straight lines between the return of the riskless asset and any point at the efficient frontier will show different combinations of the portfolio of risky assets and the riskless one. However, combinations along μ_F–M are better than combinations along μ_F–A or μ_F–B since they offer greater return for the same risk. Point M is the tangency point between the efficient frontier and a straight line passing through μ_F on the vertical axis. This straight line is called the "capital market line" (P–P in Fig. 2) and was one of the two main improvements made by the Capital Asset Pricing Model (CAPM) to the Markowitz model[9] [29]. Then, the subject will chose between a risk-free investment with a low return (μ_F), a 100% risky portfolio with a higher return (M), or a combination of risk-free and risky assets along μ_F–M. Once more, the decision will depend on the utility curves of the subject (U_1, U_2 or U_3 in Fig. 2).

[9] Being the other the definition of an index as the benchmark of the market. This index will be a market-value-weighted portfolio of all possible risky investments [29].

Unfortunately, the real world is very different from the financial world, and we cannot find a physical asset completely riskless. Nevertheless, risk (variance) differences between conventional energy sources and RES are high enough to allow risk reduction through RES diversification. For instance, Awerbuch and Berger [4] estimated the portfolio financial risk of wind power using the standard deviation as 0.02 while the same value for gas was approximately 0.10, five times higher.

4. Energy security, renewable energy sources and portfolio choice

This section applies the portfolio choice model depicted above to analyse the impact of renewables in energy security. Fig. 2 plots portfolios of energy assets, showing the optimal combination of risky energy generation assets that minimises the portfolio risk (σ, the standard deviation of cost/returns) for every expected return (μ, the inverse of expected generation costs), represented by the efficient frontier Er−Eg. For illustrative purposes, it could be assumed that Er represents a RES-dominated and Eg a conventional energy mix, for example, based on natural gas; Er is more costly (less return, μ) and less risky, while Eg offers higher returns (lower generation costs) at the expense of higher risk (higher natural gas prices variability, σ). Along Er−Eg, costs cannot be reduced (or return increased) without accepting more risk. Any energy mix below Er−Eg is inefficient insofar as its cost could be reduced without increasing its risk (or risk could be reduced without increasing costs). Energy mixes above Er–Eg are supposed to be unfeasible under the current technology and resource base. The capital market line is depicted by *P*.

Assuming that RES are fixed-cost technologies that offer a lower but more secure return, they ideally offer societies different possible energy mixes from the low return–low risk portfolio of a RES dominated one to the high return-high risk one based on conventional energy sources. Risk aversion influences the final outcome because greater risk aversion (represented by U_2 in Fig. 2) implies choosing a lower level of risk at the expense of a higher level of costs; that is, exchanging lower risk by higher costs or lower return. This risk reduction could be done by including more RES in the energy portfolio. The energy security rationale behind renewable portfolio standards or the setting of fixed objectives concerning the contribution of RES to the energy mix, as happened in the EU, follows precisely this explanation.

An optimal energy mix may also incorporate other elements, such as environmental and geopolitical concerns. As such, it is possible to attain an optimal energy mix that minimises the level of risk – economic, environmental and geopolitical – faced by a society at given energy costs [5]. RES deployment at a national level contributes to reduce expected risks related to fossil price volatility and, eventually, geopolitical events and climate change.

However, some authors highlight that the benefits of RES, both at the environmental and energy security level, could be better reached by means of other energy sources (such as nuclear) or by energy efficiency measures [46]. In any case, avoiding externalities in environmental sustainability and achieving energy security through RES deployment do not come at zero cost. For instance, electricity generation from RES entails supplementary generation and transaction costs to maintain back-up capacity, additional costs of controlling and balancing power and costs related to grid expansion.

Diversification among RES themselves is also needed to reduce the short-term variability of the main renewable energy sources (solar and wind) and technological exposure in the long run. Wind and solar energies are variable depending upon climatic conditions: deploying both types of generation capacities helps to

compensate the variability of each resource if they are not strongly correlated (sunny days can compensate for poor wind conditions and *vice versa*). Some researchers call for a joint deployment of wind and solar energy in northern Africa due to the existing symbiosis of these two types of energy [40]. Similarly, geographical diversification of a given renewable resource helps to hedge the risks of adverse climatic conditions in a particular area.

When choosing or prioritising the RES technologies to be deployed, the present cost argument should also be nuanced. In the long run, the strategy of 'picking the low hanging fruits' (for instance, wind energy, which is closer to pool prices than solar) may be detrimental if it inhibits technological and industrial developments in other renewable technologies with higher but also more steeply decreasing learning curves. This strategy introduces the problem of differentiated support systems and their optimal design.

While a renewable energy portfolio is required to achieve ambitious goals such as those set by the EU, more sophisticated policies should be implemented to appropriately support technologies that are at different development stages [51]. A simple 20% RES contribution target could lead to the deployment of present low-cost technologies (such as wind), losing the externalities that diversification among technologies and support of faster learning rates can bring. This effect is why the quantitative target is usually accompanied by technology-specific support, intended to reduce policy costs and foster the development of less advanced but promising technologies. A neutral support scheme implies high producer surpluses (for producers with lower present costs) and therefore significant present and future policy costs. However, if ill designed, technology specific support or technology banding may also imply high policy costs, which happens if deployment concentrates in the most expensive RES technologies.

Therefore, there are also some risks inherent to national RES deployment. However, in contrast to the geopolitical risks implicit in fossil fuel prices, RES-related risks can essentially be managed domestically through efficient (minimum cost) regulations, investments and technology. Nonetheless, as the recent European experience suggests[10] in reality it is difficult to achieve this goal; however, policy measures implementation mainly remain at the national level.

Obviously, domestic RES deployment (as well as nuclear) also contributes to the improvement of energy security indicators related to geographic diversification and energy dependence. If RES are deployed at a national level, they reduce emissions, dependence and the vulnerability entailed by the concentration of energy sources and origins [34].

However, this picture becomes less clear if RES deployment is extended beyond national boundaries, such as importing RES electricity from North African countries or Brazilian bio-fuels into the EU[11]. In fact, international RES trade flows may affect the level of risk perceived by consumer countries compared to a system where renewables are located within national borders. After addressing the domestic dimension, we now turn to a transnational perspective.

5. Energy security and international renewable flows

Mineral fuels (oil, gas and coal) rank first in international trade statistics, with a share of 15% of world imports. In contrast, electricity trade flows account for only 0.2% of world trade ([62],[12]), and most of the flows are not RES generated. Currently, there are only a few international RES flows, and the existing RES flows are not easy to quantify because they do not have specific codes.

Perhaps the better-known example is bio-fuels; however, even this commoditised renewable energy source lacks a truly functioning international market. In fact, Brazilian efforts concentrate precisely in creating a world market for ethanol. There are other examples of international electricity exchanges that include renewable sources. RES-generated electricity exchanges are important within the EU but scarce with third countries. In addition to the exchanges of wind energy in Northern Europe, only Spain exports so-called green electricity to Morocco through the Gibraltar Strait. The Directive 2009/28 [50] offers one of the few existing enabling institutional frameworks to foster the development of international RES trade flows, intra and extra-EU. However, before analysing the implications of Directive 2009/28 for renewable energy corridors, it is advisable to enlarge the analytical framework to include international RES flows.

Fig. 3 analyses the risk-cost impact of international RES corridors[13]. Assume that a RES corridor, e.g., electricity from solar origin generated in North Africa, is added to the available energy portfolio of the EU under the same risk conditions prevailing in the EU. If, for the same level of risk (i.e., return/cost variability), this technology happens to yield higher returns in North Africa thanks to higher insolation levels, then the efficient frontier Er−Eg is pushed upwards to Er*–Eg*. Thus, the returns of the EU energy portfolio without including solar energy from North Africa (for instance, point A) are lower than in the case where the solar contribution is additionally considered (point A*). Now, with the same set of preferences (U_1), the equilibrium shifts from portfolio B to A*, with lower risk and cost levels; point B* represents a more risk-averse result, with expected costs/returns remaining constant but the level of risk being reduced further.

In contrast, if lowering the expected cost is accompanied by an increase in risk levels along the original Er−Eg efficient frontier, the equilibrium could remain at B, without achieving any improvement in the cost-risk trade-off. There is also a worst-case scenario in which the integration of non-EU RES resources into the EU energy system outpaces cost reduction with higher risk levels. In this case, the equilibrium can be placed somewhere below the Er−Eg cost-risk efficient frontier and then becomes a suboptimal solution.

This scenario leads to the issue of risks inherent to the nature of international RES corridors. A frequent claim is that transnational RES corridors suffer from the same geopolitical weaknesses that call for a reduction of imported fossil fuels in the national energy mix: these corridors make a national economy dependent upon foreign resources. However, this argument, such as the one related to higher RES costs, is not supported by careful economic analysis. In this case, what lies behind the discussion is the common confusion between energy dependence and energy vulnerability, as we have explained in the first section. If access to international RES corridors implies further diversification of either geographical origins, energy sources, or both, the vulnerability of a country can actually decrease for a given energy dependence ratio (for instance, energy imports over consumption); that is, new resources and/or technologies from new exporting countries enter the stream. Diversification increases, and vulnerability decreases,

[10] The Spanish case is a well-known example. See, for instance, Couture [14].

[11] The IEA recognises this shortcoming in its influential 2007 report *Energy Security and Climate Policy*: *Assessing Interactions* (p. 40).

[12] Fossil fuels are classified under Section 3 (Mineral fuels, lubricants and related materials) of the SITC Rev. 3 (Standard International Trade Classification, revision 3). Their codes are 32 (Coal, coke and briquettes), 33 (Petroleum, petroleum products and related materials) and 34 (Gas, natural and manufactured). Electricity is classified in the same section but under code 35 (Electric current).

[13] This figure, as Fig. 2, is a common representation of the portfolio choice theory; see footnote 7.

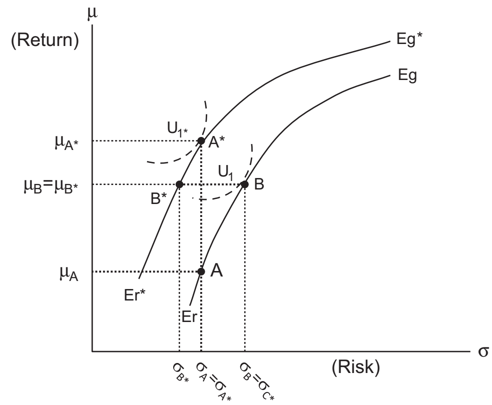

Fig. 3. Risk-cost efficient energy portfolios with international RES corridors.

even if the RES corridors came from the same countries from which conventional energies are already imported.[14]

The nature of RES also limits their capacity to serve as a driver for power politics. For instance, bio-fuel producers can try to create a cartel; however, their market power over a fossil fuel-dominated transport system is and will remain very small.[15] In a different vein, RES used for electricity generation can neither be stored as easily nor as long as fossil fuels; furthermore, storage costs would definitively be much higher with current storage technologies. Therefore, a North African country could not interrupt its green electricity supply to the EU without simply wasting the resource, at least in the short term. In the longer run, redirecting green electricity supply towards domestic markets would require transmission investments and, equally important, in addition to the loss of revenues it would increase the cost of domestic electricity above politically acceptable levels in these countries. And storage remains a long-term solution not currently or immediately available.

Presumably, the main risk dimension to be addressed is regulatory risk, which ultimately embodies a wider array of socio-political and institutional risks (this regulatory risk is far from being confined to non-EU countries). RES returns depend on regulatory schemes, and expected returns are linked to regulatory schemes credibility over the long run. Without a credible and enforceable regulatory and institutional framework, a RES-producing country can try to raise the tariffs at which it sells green electricity to its clients. Nevertheless, as explained in the above paragraph, the alternatives would be limited by small market power.

However, the relevant point here is that the shift in the efficient frontier shown in Fig. 3 can only occur in an institutional framework that delivers similar levels of regulatory risk and property rights than the levels prevailing in the importing region.

In the specific case of Europe, this fact leads to the question of whether the energy security of the EU's RES corridors depends upon its Europeanisation.[16] The following section tries to illustrate this point by analysing the EU response to the regulatory challenges implied by the integration of North African RES resources (wind and solar) into the European electricity system.

6. The Mediterranean Solar Plan: an EU framework for international RES trade

Environmental preservation is a hallmark of EU policy. For instance, the European Union has been the main player leading to the signature of the Kyoto Protocol. The EU is also one of the biggest energy-consuming regions in the world, although its limited natural endowment with hydrocarbons requires the import of 84% and 62% of the oil and gas consumed in 2010, respectively [21]. It is no surprise that the EU is keen to foster domestic development of RES, because they contribute to reduce CO_2 emissions and pollution together with fuel imports.

These are the reasons to select the European Union and its main transnational RES project, the Mediterranean Solar Plan, to illustrate the contribution of international RES trade to energy security. Besides, Desertec first, and the Mediterranean Solar Plan later, serve as a role model or inspiration to other RE initiatives like the Gobitec [13]. Before addressing the energy security issue, it would be useful to put the Mediterranean Solar Plan in the broader context of RES promotion in the EU.

The promotion of RES in the EU has been an objective since the early nineties. The first steps were taken in 1993 with the ALTENER programme, which tried to increase the share of RES in energy consumption from less than 4% in 1991 to 8% in 2005 [48]. Later, these targets were raised in green and white papers in *Energy for the Future: Renewable Sources of Energy* [10,11] to reach 12% in 2010 up from 5.4% in 1994.[17]

The last step in this direction is Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources [50] that aims to achieve in 2020 a 20% share of RES in the final energy consumption of the EU, with targets on a national basis.[18] These targets will prove to be very challenging for several countries, especially for the larger ones. Germany, France and Italy have yet to reach 40% of the target in only 10 years (2010–2020), while the Netherlands and the United Kingdom have to reach more than 70% of this target [22]. However, it should be noted that previous RES targets, such as the targets fixed in the ALTENER programme or in the *Energy for the Future* green and white papers, have been mostly achieved.

Accomplishing such objectives, even in the midst of the current economic crisis, will most likely require international RES imports (physical or virtual) within the EU but also from third countries. Indeed, the latter possibility is explicitly mentioned in Directive 2009/28. Moreover, the directive mentioned the Mediterranean Solar Plan in the preface as an example of a project 'of high European interest in third countries' whose development 'is appropriate to facilitate' ([50]: L140/20).

The Mediterranean Solar Plan is intended to integrate Southern and Eastern Mediterranean renewable resources into EU energy space and is part of the Union for the Mediterranean (UfM), which was formally established on July 13 2008 at the Paris Summit under the French Presidency of the EU. One of the six projects listed in the annex of the Paris Declaration is the so-called 'Alternative Energies: Mediterranean Solar Plan'. Despite the name of the plan, the declaration calls for the mobilisation of all RES to

[14] For instance, importing electricity with solar origin from Algeria into the EU does increase both diversification and dependence for both the EU (supply) and Algeria (demand). From a portfolio perspective, however, the diversification of sources does actually reduce vulnerability.

[15] Renewable fuel consumption in transport remained modest worldwide: the EU, one of the main world market for bio-fuels, optimistically set a 10% target for renewable fuel used within the transport sector by 2020 (art. 3.4, Directive 2009/28/EC) [50] but by 2011 this share was only 3.8% [23].

[16] The Europeanisation of energy corridors has been addressed in Escribano [18].

[17] In 2001 another milestone in the European RES policy was approved: the Directive 2001/77/EC [49]. This directive set a 22% target for RES-generated electricity in the European Union in 2010 but with distinct goals for every country. Because this target was related to the 12% share of RES in the final energy consumption in force by that time, we have omitted this target in the body text.

[18] This target is part of the EU Climate and Energy Package, best known as 20–20–20 objectives, that aims to reduce 20% of greenhouse gases and 20% of energy consumption by energy efficiency measures and increase the RES share to 20% by 2020.

export the electricity produced in the Mediterranean Partner Countries[19] (MPCs) to the EU. This plan may be the most ambitious RES corridor initiative proposed to date by the EU and the one that has attracted most attention.

The plan aims to promote the installation of renewable electricity generation capacities in MPCs, mainly in wind, solar–thermal and photovoltaic energy. The solar plan poses the initial dilemma of which technological option should be given priority. Solar thermal technology in the southern Mediterranean countries has only been deployed on a small scale, while wind generation is a more mature and proven technology. Photovoltaic energy has a major potential in the rural environment and in large and medium-sized decentralised installations. Concerning costs, wind is closer to present pool prices; however, learning curves – and consequently future cost reductions – are more promising for thermo-solar and photovoltaic energies. As explained in above, diversification among RES would help to hedge technological exposure while reaping the benefits of balancing present and expected cost structures.

The plan also contemplates the construction of high-capacity High Voltage Direct Current (HVDC) lines to transmit the green electricity generated in the southern shore of the Mediterranean to the EU. The development of electricity corridors between the Mediterranean Partner Countries and Mediterranean Europe, and between the latter and the rest of the European continent, is needed to transmit green electricity to the EU. Given that electricity systems in the southern shore of the Mediterranean are much weaker than systems throughout the rest of Europe, the improvement of its electricity grids and intra-regional interconnections will also prove necessary. Connecting their grids with the EU and between themselves enhances MPCs' system but requires a modernisation effort. A significant increase in the contribution of renewable energies could signify a challenge in terms of additional improvements for MPCs' system, given that renewable energies require important network capacities and greater flexibility of the system to be able to manage it appropriately.

However, apart from infrastructure and technical questions, for the purpose of this article, the most interesting issue is how to economically manage these flows to achieve risk-cost optimality, that is, as explained in the previous section, how to regulate a transnational RES corridor network, such as the Mediterranean Solar Plan, in a manner in which costs could be reduced without increasing risk. To do so, regulatory and institutional conditions and political stability are key requirements for RES investment, as noted by Komendatova et. al. [39] and Lüthi and Wüstenhagen [43]. Not surprisingly, these authors have found that regulation is the main risk perceived by RES investors: the consequences of regulation are more dangerous to the projects, and its probability of occurrence is the highest among all the others risks, reaching 90%. Following regulation is the risk of political instability (although the interviews included in their results were conducted prior to the 'Arab spring'); terrorism is in only fifth place. In spite of recent events, this low ranking seems to match the fact that terrorism against energy infrastructures is very rare in MENA (Middle East and North Africa) countries outside Iraq. Some authors explain it by the indiscriminate effects of energy outages and by the low political symbolism attached to energy targets (see [57,60]). Another explanation is the low fear-creation potential of blackouts induced by terrorist attacks [42].

The measures to reduce these types of risks can be split into two groups: (a) financial aid, including RES support schemes (i.e., FIT), public or private insurance, low rate loans or private–public partnerships; and (b) reform programmes leading to structural change and modernisation [38]. The second approach appears to be more attractive; however, the first approach is undoubtedly more pragmatic and, given the EU's self-imposed restrictive timeframe, easier to develop. Furthermore, EU members have also resorted to RES support schemes to foster their own RES development, with feed-in tariffs (FIT)[20] being among the most-successful ones [12]. Although FIT have been under consideration for a while, some developing countries such as Morocco or Mexico have decided not to use them, and Brazil is phasing them out [35].

However, to foster RES investments across the Mediterranean region, regulatory and institutional conditions must be levelled such that risk is perceived to be at similar levels in both the EU and North African countries. The first step, then, is to analyse the institutional and regulatory framework built by the EU.

Directive 2009/28 acknowledges that one of its goals lies in the facilitation of cross-border RES support without necessarily affecting national support systems. To achieve this objective, the directive introduces cooperation mechanisms among member states that allow them, first, to agree on the level of support granted by a member state to the RES coming from another member state and, second, to agree on how to share these RES for the purpose of achieving the directive's declared objectives themselves. The flexibility measures contemplated by the directive include statistical transfers, joint projects and joint support mechanisms. Statistical transfers refer to the exchange of green certificates. For instance, the green certificates generated by solar energy in Southern Europe (if they exceed the respective national objectives) can count toward the objectives of a Northern EU member state. This exchange can be done, or not, within a joint project – e.g., a jointly owned solar farm – and can benefit, or not, from a commonly agreed joint support mechanism.

Regarding the generated RES, the conditions for green electricity (the electricity that is green certified) imported from third countries are not so flexible. First, the conditions do not allow statistical transfers between an EU Member State and a third country. Only physical electricity transfers can be accounted towards member states' RES contribution targets. To ensure additionality,[21] only green electricity from installations or newly added generation capacities in existing plants starting operations after the directive entered into force can be considered in the fulfilment of national RES objectives. Member states can implement joint projects with third countries, including in their national objectives the green electricity imported from the third country and consumed in the EU. In the absence of existing – but projected – operative interconnections, the member state can include in its national objectives the green electricity that has been agreed on with the third country until the needed infrastructure is in place.[22]

Given that the directive does not affect national support systems, there is no obstacle to implement joint support systems for these joint projects with third countries. The only limitation, which also applies to intra-EU projects, is that to count towards national objectives, the imported green electricity cannot benefit from support schemes in the third country, with the significant exception of investment support for the construction of

[19] Mediterranean Partner Countries include the twelve Southern and Eastern Mediterranean countries that take part in the Barcelona Process that started in 1995 plus Libya, Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Mauritania, Morocco, the Palestinian Authority, Syria, Tunisia and Turkey.

[20] A feed-in tariff (FIT) is a RES support scheme designed to accelerate investment. It usually comprises three key elements: guaranteed grid access; long-term contracts for the electricity produced and purchase prices based on the cost of generation.

[21] Additionality, such as in the Clean Development Mechanism, is introduced to foster the deployment of new generation capacities, instead of profiting from already existing plants.

[22] The construction of the interconnection should start before 2017, and its operation should begin between 2021 and 2022.

installations. Nevertheless, even if statistical transfers with third countries are excluded by the directive, *de facto* the directive offers such countries the opportunity of including statistical transfers by joining the Energy Community Treaty. As the directive clearly states, the contracting parties of the treaty can benefit from the same flexibility measures than EU Member States, if it was so decided.

In sum, the new directive contemplates favourable conditions for the implementation of joint projects between member states and third countries and allows the introduction of joint support systems commonly agreed on with a third country. For instance, a member state can extend its support system, e.g., a feed-in tariff system such as the ones existing in Germany or Spain, to green electricity coming from a third country. Given that a feed-in tariff system is linked to production costs, it will allow the differentiation of bonuses granted to national and third-country green electricity, with North African countries receiving a smaller support given their lower generation costs for solar – and in some cases wind – energy.

Thus, Directive 2009/28 introduces an institutional framework that allows the emergence of joint regulatory mechanisms between member states and non-EU countries. These mechanisms can reduce regulatory risks, allowing the upward shift of the risk-cost efficient frontier to lower risk-cost combinations. However, to align regulatory risks with those risks prevailing in the EU, normative convergence towards the EU *acquis communautaire* in the field of renewable energy would also be needed. Without some degree of normative convergence, these joint projects and support mechanisms can fail to become operational. Issues such as the interoperability of electricity systems, support mechanism control, grid access, transparency in public procurement, authorisations and certifications, among many others, require a minimum degree of normative harmonisation, both at the regulatory and technical level. In short, these elements call for the Europeanisation of Mediterranean energy corridors [18].

One of the possibilities to provide a deep integration framework based on normative convergence is to extend the Energy Community Treaty to North African countries. The general implementation of this treaty would require to model North African energy systems to be similar to the *acquis communautaire*, something that is highly unrealistic given the preferences of North African countries, especially those that are significant hydrocarbon producers and want to keep their energy sector under government control, something incompatible with the treaty provisions. The treaty contains ownership and unbundling provisions as well as transit and access rules that under present conditions are not applicable to most EU neighbours, both south and east.

However, for the purpose of integrating RES in the EU energy space, a rigid and complete implementation of the EU energy *acquis communautaire* is most likely not required. On the contrary, the Mediterranean Solar Plan illustrates the case of a more restricted, differentiated convergence over a relatively fringe issue (RES versus the more sensitive issue – for energy actors and lobbyists – of conventional energies) [18]. This differentiation has a normative and a geographical dimension, with eventual joint projects and support schemes being implemented with different third countries under diverse agreed normative convergence conditions.

In this regard, the Mediterranean Solar Plan can be understood as an essay to design an institutional model for the integration of non-EU RES corridors into the EU energy market. It is an institutional and market approach, but it can be projected geographically in a differentiated manner. If well designed, it could leave both producers and consumers better off in terms of combinations of costs and risk. This design, the regulatory dimension of the RES corridor, which could be described as a normative corridor, is key to evaluating the contribution of RES to EU – and North African – energy security.

Finally, to implement an ambitious project such as this, it is necessary to have steady and strong support from all the parties involved. This requirement is too often taken for granted or even forgotten; however, without any doubt, this support is key to success. Using the plan as a development driver for the Mediterranean region will be a safe strategy to gain support from the Mediterranean Southern shore [44]. Some estimations show that RES could become this driver, and there are countries willing to try.

For instance, Morocco, considering its internal drivers combined with its RES potential and geographic location, is most likely the best-positioned country in the Southern Mediterranean region to implement the Mediterranean Solar Plan [19]. Furthermore, Morocco has expressed its will to participate because this project could become a significant driver of development as shown by recent estimations. For instance, De Arce et al. [15] conclude that RES deployment entails significant economic opportunities for Morocco in terms of GDP and employment. In the proposed scenarios, the estimates for the economic impact on GDP vary from 1.17% to 1.9% at the end of the period (2040), directly and indirectly creating the full-time equivalent of 267,000 to 482,000 jobs. Therefore, the potential of RES as development drivers cannot be ignored, especially for the developing economies of the Southern shore of the Mediterranean.

7. Conclusions

Energy security is a multidimensional concept that has been increasingly used since the beginning of the 21st century. Efficiency and diversification are the keys to improve energy security reducing energy vulnerability. This article will deal with diversification through international RES flows.

Following the classification of energy risks proposed in this article, the most important differences between RES and conventional energy sources appear in secondary energy risks (such as price volatility, physical supply disruptions or environmental damages) rather than in technical or geopolitical primary risks. RES could also be used to reduce vulnerabilities. Domestic RES contributes to energy mix diversification, but international RES trade flows add geographical diversification of energy suppliers and a new mean of transporting (HVDC lines). Thus international RES flows are strong candidates to improve energy security.

Although conventional wisdom states that renewable energy increases costs and risks of the energy system, from a portfolio-choice perspective, domestically produced or imported RES could improve the energy risk-cost trade-off. The key issue here is that modern RES such as wind or solar are zero marginal-cost technologies that do not need fuel to generate power and that thus lessen the exposure of the energy mix to price volatility related to conventional fossil fuels.

Another frequent claim is that international RES corridors suffer from the same geopolitical weaknesses than imported fossil fuels such as oil or natural gas. Although these corridors can increase an energy system's dependence, they could lessen its vulnerability, which, for the purpose of this article, is the relevant result. Furthermore, the very nature of RES limits its capacity to serve as a driver for power politics: petro-politics cannot easily turn into RES-politics. Thus, the main risk dimension to be addressed regarding international RES trade is regulatory risk rather than geopolitical concerns usually threatening oil and gas supply. For green electricity imports to increase energy security, it is necessary that appropriate normative measures be in place to

minimise regulatory risks between energy consuming regions and foreign RES producers.

This study applies these results to the EU Mediterranean Solar Plan, the main current project projecting massive international RES electricity trade. Our results suggest that to foster RES investments across the Mediterranean, regulatory and institutional conditions must be levelled so that risk is perceived to be at similar levels in both the EU and North African countries. Although Directive 2009/28/EC is a good step in this direction and can help to reduce regulatory risks, it is not sufficient because further normative convergence to the EU *acquis communautaire* in the field of renewable energy would be needed. Thus, the Europeanisation of Mediterranean energy corridors would be a solution, although a rigid and complete implementation of the EU energy *acquis communautaire* appears not to be required and not even advisable.

The Mediterranean Solar Plan constitutes an effort to institutionalise a consistent model for the integration of non-EU RES corridors into the European energy market. However, only a well-designed institutional and regulatory framework could optimise the risk-cost frontier for both sides of the Mediterranean. To successfully implement this ambitious project, the EU must not forget that gaining support from Mediterranean neighbours, on the basis of the project contribution to energy and economic development, is not an option but rather an urgent imperative.

As a corollary, it has been shown that green electricity from RES, whether domestically produced or not, could improve energy security. However, regarding international RES trade, such improvement could not occur unless some measures to balance the regulatory energy risks between exporting and importing countries had been taken. The Europeanisation approach appears to be the logical answer from Europe; however, this approach has to be tailored to consider the preferences from the Southern and Eastern Mediterranean countries.

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